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Estimating effects on emissions of sharing

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Abstract: Sharing products and services might have environmental consequences. This report is partly a literature review on the topic, but also an attempt of estimating the effects on emissions of different sharing schemes in the SHAR(e)ON project. The four different sharing schemes we have investigated are: community supported agriculture, sharing in local communities, sharing of cabins, and car sharing. The estimates are presented as scenarios or illustrations informed by literature or other parts of this project, not as what is likely to happen to emissions for different sharing schemes.

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Contents

1 Introduction

Sharing products and services might have environmental consequences. We try to quantify the effects on emissions by considering what sharing replaces. Sharing can have many different direct and indirect consequences, but we try to illustrate the impact on emissions by showing the consequences of replacing one product or activity by some other with sharing. These are not calculations of what will happen in terms of emissions because of sharing, but different scenarios to illustrate what the emission impact might be. We will present different cases to indicate a range of possible emission outcomes. This sheds some light on the potential range and gives indications both on what areas of sharing might be important in terms of reducing emissions and how sustainable sharing schemes might be better designed.

1.1 Emission calculations

Our analysis is based on emission estimates of different products and activities. For some cases, we will only consider the direct emissions, such as comparing the direct emissions of cars and electric vehicles. For other cases, we will take into account the life cycle emissions, so that the carbon footprint of products is estimated with Life Cycle Assessment (LCA, sometimes Life Cycle Analysis). In cases where the direct emissions have the lion share of the LCA emissions, we focus on the direct emissions, while for products where emissions mainly come from production phase, we consider the LCA emissions.

1.1.1 LCA

The purpose of LCA is to estimate environmental impacts associated with all life stages of a product, from production chain to disposal, see also van Oort and Andrew (2016). Because results based on different LCA calculations vary very widely depending on assumptions made and methodologies used, international standards have been established. However, the range of permissible assumptions and methodologies mean that the results from LCAs should be interpreted with care.

1.1.2 Comparing activities and products

We can most often easily calculate the emissions of a product or an activity. The challenging part is to compare to a relevant reference case, so what sharing is replacing, and what our system boundaries for the analysis are. In most cases, we will be comparing apples with oranges, and not apples with apples.

LCA is made to allow comparability between products that serve the same purpose, so the environmental consequences of taking a choice becomes quantified. Different cases should be compared with a “functional unit”. The process of identifying this functional unit is critical as different choices can lead to significant different analytical results. As a result, the choices made of the functional unit should always be very clear for LCA results. As a product might serve different purposes and interests, it is generally not possible to choose a functional unit that makes them perfectly comparable, and simplifications are necessary. For instance, travel between two locations with electric bike and car is in one sense serving the same transportation need, but the two transport modes have different properties and qualities, such as health aspects. Averages are not only unavoidable but also entirely necessary, as data for one specific are unlikely to be representative for the average. In LCA work both uncertainty and sensitivity to different parameters should be addressed. All stages of the LCA might be difficult to include, such as how much of the food is thrown as waste by the consumer.

Some emission cuts will be one-off (e.g. avoiding buying a drill), while others will give annual cuts (e.g. travel mode shifting).

We will focus on the direct and indirect effects and compare different cases with a functional unit. However, induced effects and complex processes may occur. Among those are rebound effects (Hertwich, 2005). For instance, participating in sharing can reduce the costs for the participants. The money saved can be used on something else that leads to emissions. Rebound effects could be very different if the saving is

- Received as a payment spread over a year (e.g. 3,-/day), e.g., reduced daily travel cost by mode shifting.
- Received as a one-off payment (e.g. 1000,- in the hand), e.g., by not buying a new drill
- Similarly, saved from today's expected expenditure or saved from annual expenditure

To simplify, we calculate emissions at a personal level or per item, which is easy to compare with the annual emissions of an average Norwegian person.

2 Literature review of emission impacts of sharing

Several studies have attempted to quantify the environmental impacts of sharing, especially car sharing, but the interactions leading to changes in greenhouse gas emissions are complex and not fully understood (Frenken and Schor, 2017). There are almost no comprehensive studies of its impact. A common belief is that sharing is less resource intensive as less goods may be needed (Schor, 2014). However, sharing is also influencing the economy leading to different indirect and complex effects. If sharing of goods and services leads to less production of new products and possibly less and/or more sustainable use compared to private ownership, the sharing economy may assist a shift towards a low-carbon-emissions society (Cohen and Kietzmann, 2014). Skjelvik et al. (2017) recently did a literature review on sharing in a Nordic context and focused on four sharing segments: Transportation, housing/accommodation, services, and other, smaller capital goods. Their mapping found that the largest emission reduction potential is in transportation, while renting of smaller capital goods can also lead to emission reductions. The Swedish Environmental Research Institute IVL estimates that the second-hand market in five European countries reduced CO2 emissions by 12.5 million tons in 2015 in their "best case" scenario where they assumed that buying an used item replaced buying a new corresponding product (Schibsted, 2016).

Most of the recent studies on the carbon effects of sharing is on car-sharing. Positive effects are found for the majority of households joining car-sharing schemes: the increase in emissions by gaining access to cars is small, while the decrease in emissions by getting rid of vehicles and driving less is larger (Martin and Shaheen, 2011). This result is dependent on that households entering the sharing schemes to some degree sell their cars and travel less by car than before, as the sharing scheme help people that otherwise would not have access to cars. Firnkorn (2012) found that the effect of Daimler's car2go service reduced the total number of cars, which might imply a potential for reductions in carbon emissions. A survey in the Netherlands found that car sharing leads to 30% less car ownership and 15% to 20% fewer car kilometers than prior to car-sharing. The reduction in CO2 emissions related to car ownership and car use was estimated to between 13% and 18% (Nijland and van Meerkerk, 2017). Chen and Kockelman (2016) found that car-sharing members in the US reduced their individual transportation emissions by 51% upon joining a car sharing organization. However, there are also counterproductive effects. If for instance car-sharing services become easier to use than public transport, it may increase emissions as well as congestion and accidents. Emissions are reduced by mode shifting and avoided travel, but also by saved parking infrastructure and reduced fuel consumption. When they account for indirect rebound effects, almost half of the reduction is counteracted. The size of the rebound effect is depending on how the transportation saving is spent. In a Norwegian setting, Briceno et al. (2005) find that the this rebound effect is small if savings are spent uniformly across non-transport items, while the rebound effect is dominating over any emission reductions if savings are spent on air travel. Druckman et al. (2011) investigated how large the rebound effect could be for UK households. For average spending of money, the rebound effect was estimated to be 51% for savings in food consumption and 25% for savings in travel. The average of three cases were 34%. Depending on what goods and services the re-spending goes to, the rebound effect can be as small as 12% or much larger than the initial emission reduction. Given these counterproductive effects, Demailly and Novel (2014) ask if more sharing means consuming more, and call for more studies on the environmental effects of the sharing economy, which is also asked for by Frenken and Schor (2017).

Literature on emission impacts of community supported agriculture is sparse, but several studies have discussed issues related to local food. Coley et al. (2009) compared emissions from food distribution with farm shop and mass distribution approaches and found that the last distance, labelled as "food miles," of travel makes a difference. For their UK case they found that if customers must drive more than 6.7 km back and forth to purchase vegetables, that will lead to greater emissions than a traditional system with mass distribution. Distance is not the only relevant factor, but mode of transport, the efficiency of the distribution system and the loading capacity of the vehicles are also important aspects. Schmitt et al. (2017) states further that the literature shows that emissions from farming are more important than emissions from transport. Relocalization of the farming to less ideal would then increase the global emissions, even though distances to the consumers are reduced. Here, we focus mainly on climate issues, but the food system has a range of sustainability issues that could be discussed (Schmitt et al., 2017). Cleveland et al. (2015) argue for that the distance travelled should not be the only indicator to evaluate alternative food systems. Kulak et al. (2013) find the largest mitigation potential with urban community farm is to farm crops that provides the largest yields in the local conditions and produce food that can replace food from CO2-intensive greenhouses and air-freighted food. If sharing, as through community supported agriculture, causes a change in diet, that may have emission impacts. Food products from high to low emissions are ruminant meat, dairy (cheese), pork, chicken, fish, grain, vegetables, and fruit (van Oort and Holmelin, 2019). The literature on community supported agriculture indicates also that reduced waste is possible as limited packaging is used and household equipment is often re-used on-site, but we have not found information whether food waste is reduced by the consumers or not. This literature indicates also that participants report that they increase consumption and variety of fruits and vegetables (Cohen et al., 2012; Curtis et al., 2013; Wilkins et al., 2015; Hanson et al., 2017; Vasquez et al., 2017), while they are not clear on if that entails reduced meat consumption.

3 Sharing cases

In this project, we have investigated four different sharing schemes: community supported agriculture, sharing in local communities, sharing of cabins, and car sharing.

3.1 Community-supported agriculture

Joining a community-supported agriculture (CSA) may affect greenhouse gas emissions through various effects, such as changed transportation patterns, changed diets, changed waste behavior, and changed production patterns. This section focuses on transportation and changed diets, but CSA can also function as a form of climate adaptation, providing routes for farmers to explore more resilient modes of production in the face of climate change.

In the standard supermarket model, produce is collected by truck, transported to a distribution hub, distributed to supermarkets, and customers travel to the supermarkets.

The two farms considered in the project use different distribution models. Virgenes farm, situated near Larvik, provides delivery at pick-up points near to its customers, while Øverland farm, situated near Oslo, requires customers to come to the farm to collect produce. The truck from the Virgenes farm drives to the pick-up points every second week. In both cases, the food requires transport between the farm and the customer, and Figure 1 and Figure 3 show these distances if transportation was direct, calculated using the home addresses of customers, the addresses of the farms, and shortest travelling distances between the two. However, while for Øverland farm, each customer will travel the distance from their home to the farm and back again in their private vehicle, for Virgenes farm the delivery truck will drive directly to the pick-up points, leading to a short drive for the customers to the pick-up point, resulting in lower travel distance overall. Further, when the truck is loaded the emissions per kg of produce per km travelled is lower than a private passenger vehicle (Coley et al., 2009). Passenger cars transporting 30 kg of groceries each would generate more than 20 times the CO2 per kg-km as a 3.5t truck that's 50% loaded, given the emission factors in DEFRA (2019). The type of delivery by the Virgenes farm will probably lead to relatively smaller emissions than the Øverland farm model.

We estimate the greenhouse gas emissions if all the customers hypothetically were to drive to the farm to collect the produce. In our estimate, we assume that the customers drive an average Norwegian car in the year 2020 based on the emission factor database HBEFA3.3 (2017), resulting in direct emissions of 0.13 kg CO_2-eq. per vehicle km. Newer fuel-efficient vehicles and electric vehicles will lead to lower emissions. The distance between the customers and Virgenes farm is given in Figure 1. Two maxima are observed, indicating that many customers live in Larvik and surrounding areas just some tens of km from the farm and another cluster in and around Oslo at about 100 km from the farm. The CO_2 emissions distribution for these journeys is given in Figure 2. The average CO_2 emission is 16 kg per return trip.

Most customers of Øverland farm live close by, as this farm is situated near Oslo. The average distance between customer and farm is 12 km, and most customers live within 20 km of the farm. The average CO_2 emission is 3.2 kg.

The literature indicates that participants increase consumption of fruit and vegetables; however, we have not found studies that found decreases in meat consumption. In the CSA case study, we interviewed 20 CSA members at the beginning and the end of their first year of membership. Most of the interviewed self-reported an increase in consumption of vegetables as a result of being CSA members. They also reported buying less food from their local store when the farm produce was in supply. Two had become vegetarian in this process, three had reduced their meat consumption while two had increased their meat consumption as a result of access to meat from Virgenes produced in accordance with their views on animal welfare. A few were vegetarian before they became CSA members. These findings are based on the self-reported changes among the interviews, so it is difficult to assess the impact on emissions. However, one meat free day a week compared to average consumption will reduce LCA emissions by 53 kg CO2-eq. per year according to calculations based on the study Steen-Olsen et al. (2016). Further, a similar study (Stamm, 2015) based on the same datasets estimate that a transition from average meat consumption to meat free dinners will reduce the annual LCA emissions of 180 kg CO2-eq. per person. In comparison, becoming vegetarian reduces emissions by 211 kg CO2-eq. and becoming vegan 479 kg CO2-eq. While read meat has the highest emissions per kg, with beef from young bulls around 19 kg CO_2-eq. per kg (van Oort and Andrew, 2016; van Oort and Holmelin, 2019), some emissions remain even with a vegan diet. The emission level from the livestock raised from these two specific farms can be quite different than the average, as local variations are large and that these farms may not follow standard practice. Further emission reductions are possible with reduced food waste.

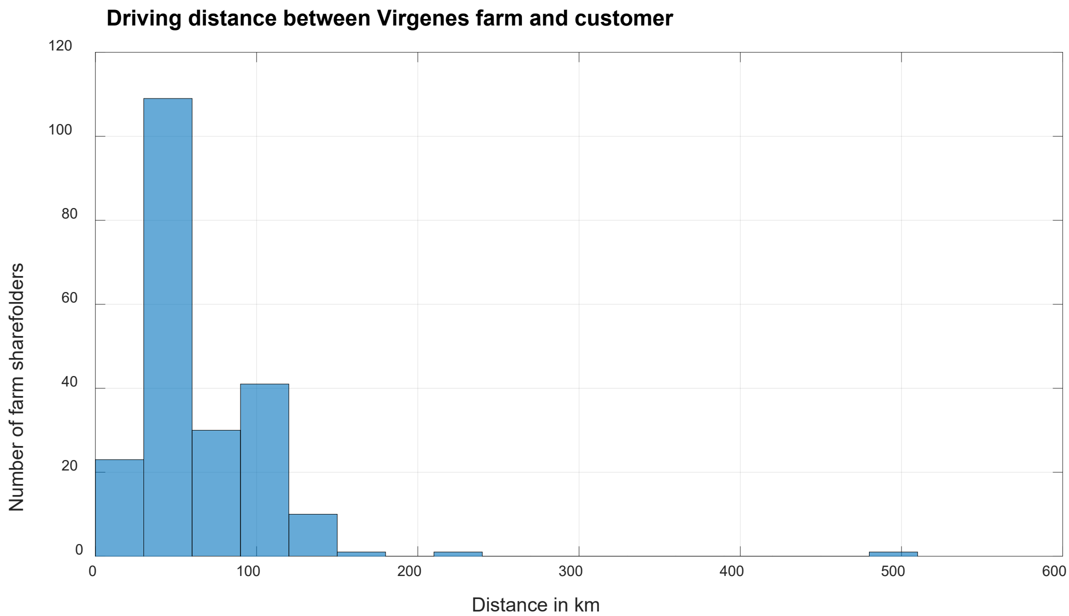

Figure 1: The travelling distance by road from Virgenes farm to the home address of the customers.

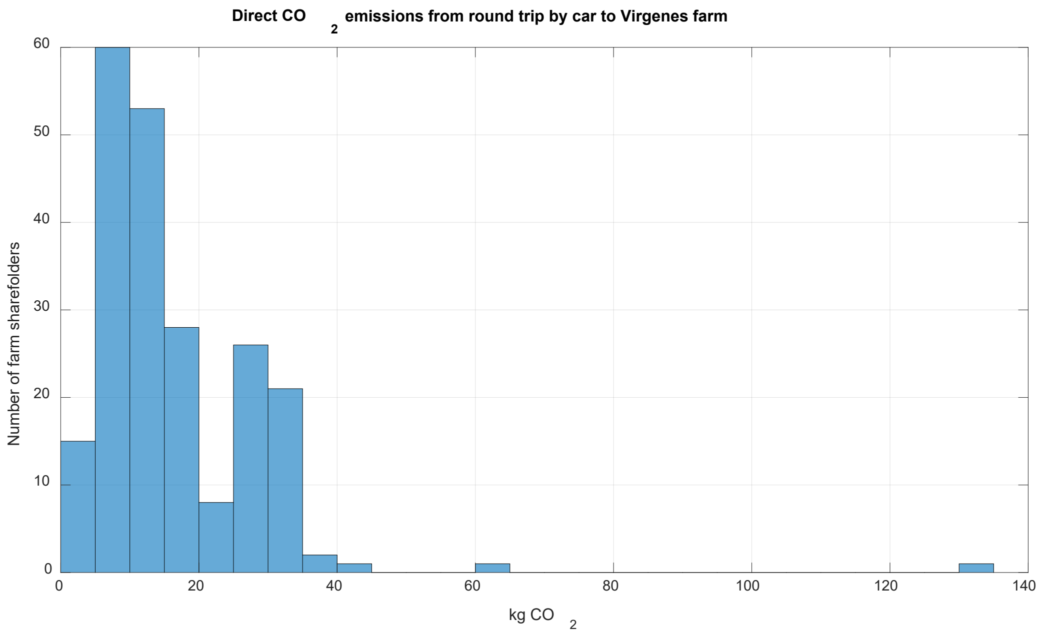

Figure 2: The direct CO2 emissions from a round trip by a typical farm between customer address and Virgenes farm.

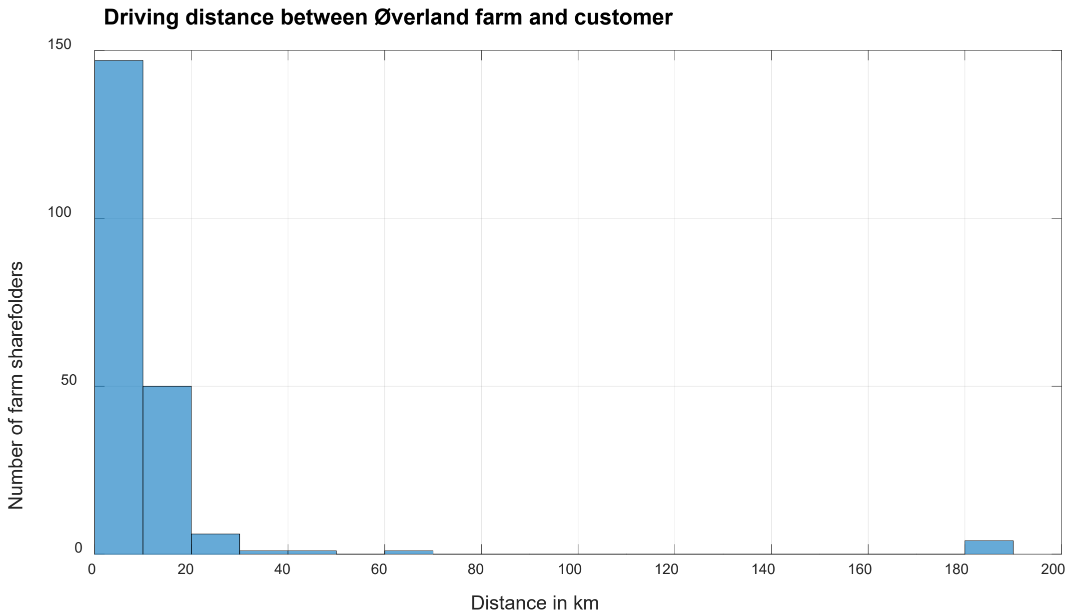

Figure 3: The travelling distance by road from Øverland farm to the home address of the customers.

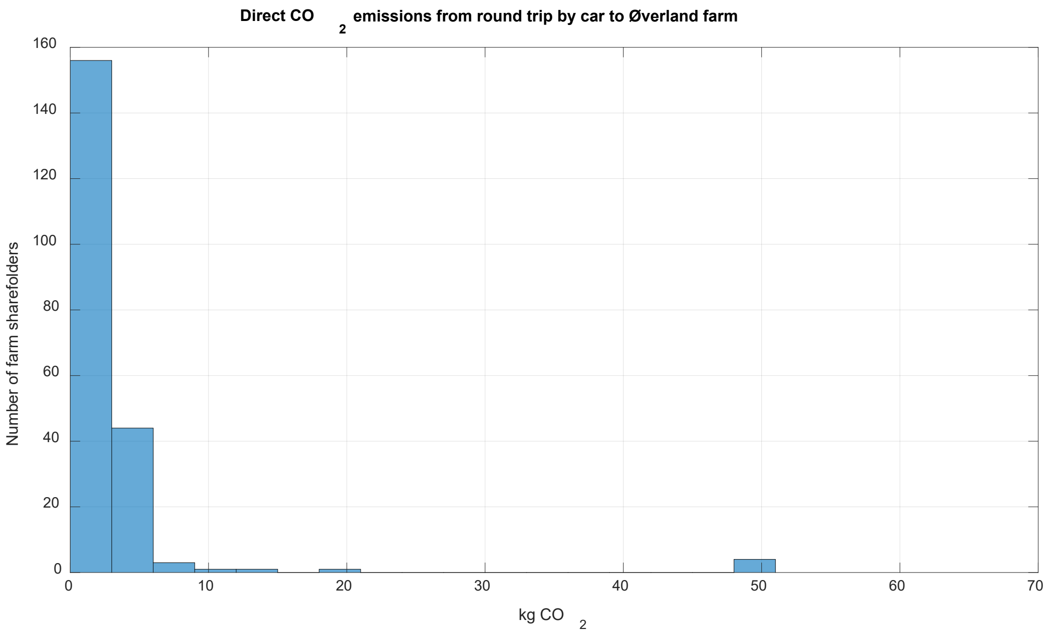

Figure 4: The direct CO2 emissions from a round trip by a typical farm between customer address and Øverland farm.

3.2 Sharing in local communities

For tools that can be shared, the potential for sharing is that less items are needed and emission from producing the tools are reduced. As for other sharing schemes, rebound effects should also be accounted for, as the saved money will likely be spent on something else.

3.2.1 Tools

Certain tools are seldom used but are necessary for particular tasks. An electric drill is a clear example, with it often being said that the average drill is used for only a few minutes of its lifetime, although we can find no origin for this claim, which is probably based on untested assumptions rather than any survey.

WRAP (2010) finds that the life-cycle emissions from one electric drill is 28 kg CO_2 eq. Less than 2% of these emissions comes from the use phase, precisely because the average drill is rarely used and therefore little CO_2-generating electricity is consumed during use. Indeed, as Figure 5 demonstrates, the electric drill is a stand-out example in this respect. Hence, the most efficient way of reducing emissions from electric drills is to have fewer drills cover total demand.

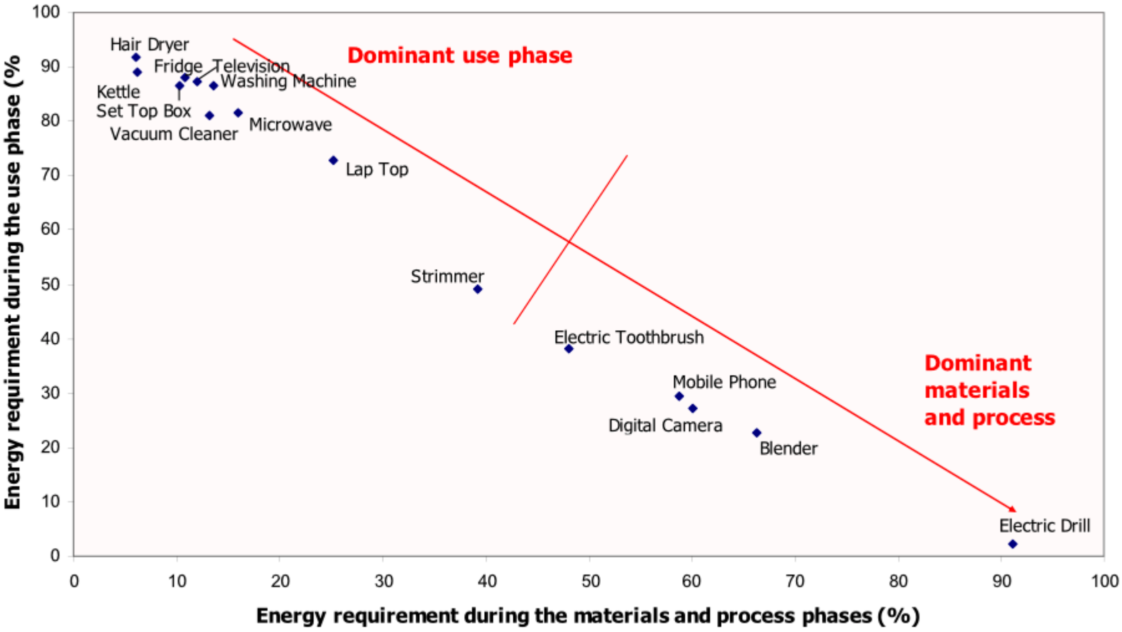

Figure 5: Proportion of life-cycle energy requirements for a range of consumer electronic products (WRAP, 2010).

As with other sharing cases, there will be rebound effects with sharing of drills resulting from the money saved, but given how little drills cost, we expect these effects to be small, just as emissions from buying one drill is small.

We compare the example of a battery-powered drill shared within a group of 20 households with a scenario of five of those households owning their own drill. It is likely that individually owned drills are also shared between households. Since the amount the drills are used has a negligible effect on lifecycle emissions, we need make no assumptions about differing levels of use in the two scenarios. Quite simply, the shared drill results in about 28 kg CO2-eq., while the individually owned drills together result in about 140 kg CO2-eq. When divided by the 20 households, these come to 1.4 kg and 7 kg CO2-eq., respectively, over the lifetimes of the drills. The difference of 5.6 kg CO2-eq. is a relatively small impact, particularly since it must be shared over the life-time of the drill, perhaps 5–10 years; for context, the average annual carbon footprint from a Norwegian household is more than 20 tonnes CO2-eqivalent per year (Steen-Olsen et al., 2016).

3.2.2 Trailer

A trailer is another example of a consumer product that is not often in use, suggesting that sharing might result in lower life-cycle emissions.

We were unable to find existing literature on the life-cycle emissions of trailers. Instead we make the approximation that the trailer's production emissions are largely from the manufacture of steel, a highly energy-intensive process.

The type of trailer purchased in this case study weighs about 300 kg, without load, and almost all of that weight will be steel. Given a global average CO_2 intensity across the steel industry of 1.9 tonnes of CO_2 emitted per tonne of steel produced (World Steel Association, 2020), the production of just the steel required for the trailer's manufacture results in the emissions of about 570 kg of CO_2. However, the steel in the trailer can be made of recycled steel and the steel can also be reused, both substantially reducing the emission estimate. This extra emission should be proportioned out over the lifetime of the trailer. Hence, the annual emission saving of one trailer is small. However, other issues may change the picture.

Emissions associated with use of the trailer are associated with the use of the car, and trips with a trailer will lead to higher per-km emissions because of extra load on the car's engine. Many of the electric cars on the market cannot tow a trailer. If increased accessibility of the trailer leads to increased usage, then emissions will also increase because of increased driving distance.

We find no literature to inform how trailer use changes with access to a shared trailer, whether free or paid. A rebound effect is possible, as easier access to a trailer potentially leads to more usage. It is very difficult, therefore, to see in advance how trailer usage might change with the introduction of a free trailer shared among households. In particular, such a scheme would come in addition to existing trailer-sharing schemes: service stations around the country lend trailers for a small fee, and trailers can sometimes be borrowed for free from retailers. Effectively, trailer sharing exists already, and purchasing a trailer to share among a group of households might result in both an increase in the number of trailers and in their use.

In the case where a trailer-sharing scheme is introduced to the household grouping, and that this trailer is entirely additional rather than a replacement for existing services, emissions will increase by the construction emissions of the trailer divided by the lifetime years.

3.2.3 Electric bicycles

The availability of electric bicycles has been shown to increase cycling and reduce use of cars significantly (Fyhri et al., 2016; Ydersbond and Veisten, 2019). In this case study, we investigate the hypothetical introduction of 10 shared electric bikes for the use of residents in Konnerud, near Drammen. Some number of these residents work and shop in Drammen, but given that there is an elevation difference of approximately 300 m and distance of 8 km between the two locations, it is perhaps reasonable to assume that few make this journey either on foot or standard bicycle.

To explore the climate effect of the introduction of electric bicycles, we first assume that their availability does not affect the number of private vehicles owned, but rather replaces some fraction of these journeys.

The journey by car between Konnerud and Drammen, with a distance of 6 km and average gradient of 4%. The emissions per km are higher in the climb and lower in the decline, while the net is slightly above average conditions with now gradients. The emission factor database HBEFA3.3 (2017) estimate that an average car in Norway in 2020 has direct emission of 216 g CO2/km in the climb and 70 g CO2/km in the decline. The average is 143 g CO2/km, compared to the average of 132 g CO2/km for flat conditions. When we add 18 % to account for well-to-pump emissions, the well-to-wheel emissions per return trip is then 2.0 kg CO2.

According to Google Maps, this trip takes about 10 minutes by car, and by standard bicycle perhaps 38 minutes up and 16 minutes down. Even with an electric bicycle, where the upwards journey might be considerably reduced, this trip by bicycle is possibly longer than many would consider for daily commuting.

To estimate the emissions resulting from use of the electric bicycle we make some simple assumptions: the electric bicycle requires less than 0.02 kWh/km (Fishman and Cherry, 2016) and we use the Nordic electricity mix factor of about 0.6 kg CO_2/kWh (Nordic Energy Research, 2018). These assumptions result in emissions of about 0.01 kg CO_2 per return trip on the electric bicycle, which is negligible in the context (less than 1% of driving a car).

When comparing only the use phases, then, if every electric bike can replace two daily return trips with cars between Konnerud and Drammen, that would save about 15 tonnes CO_2/year, given the assumptions we have made.

More important are the emissions associated with the other phases of the life cycle of the electric bicycle. Weiss et al. (2015) estimate the LCA emissions of electric bicycle to 25 g CO2/km, with only standard bicycles having lower LCA emissions.

3.3 Sharing of cabins

There are many forms that holidays can take, ranging from staying at home to trips to distant countries. When considering the climate effects of cabin sharing, it is important to consider whether use of a shared cabin adds to or replaces alternative holiday plans. A holiday is more than just taking time off from work and school, and potentially also combines new experiences, time off from household duties, warmth and sunshine during winter, time spent in nature, etc. In general, therefore, an overseas trip provides quite different 'services' to the vacationer than a trip to a shared cabin.

In this case we will look at the sharing of cabins facilitated by The Norwegian Trekking Association (Den Norske Turistforening, DNT), which operates over 500 cabins throughout Norway. Staying at these cabins can be seen as a type of sharing, as these cabins can potentially replace private huts or replace alternative leisure trips. However, we have not found documentation of whether the availability of the DNT cabins reduce ownership of private huts.

There are many possible scenarios for use of DNT cabins, and we necessarily constrain our discussion here to some selected examples.

First, we compare the CO_2 emissions of travelling by car from Oslo to a cabin in the nearby surroundings (Sæteren gård as an example) and in the mountains (Haukeliseter as an example). We choose Haukeliseter as this is the cabin with the most overnight visits of all cabins in 2017 (450,763). The distance from Oslo to Sæteren gård is about 21 km giving CO_2 emission of about 6 kg for a round trip, assuming an average Norwegian car in 2020 by the emission factor database HBEFA3.3 (2017) with direct emissions of 0.132 kg/km. For a trip to Haukeliseter, the CO_2 emission is about 74 kg for a round trip given a distance of 280 km.

Our second example is a cabin in the forests within Oslo's city limits, Fuglemyrhytta, which can be arrived at using public transport (metro) and a hike of 2–3 km. The emissions from transportation for this trip is, hence, minimal. For this example, we assume also relatively simple meals, since food and water need to be carried in, and clearly there is an absence of other purchasable services at the holiday site. The cabin has natural gas for cooking purposes, and (assumed carbon-neutral) wood-fired heating, and beyond this there may be no CO_2 emissions in addition to what one would generate simply staying at home.

As an example of an alternative holiday, Gran Canaria is a very popular destination for Norwegians, with over 330,000 trips in 2019 (AENA, 2020). We find the total CO_2-eq. emissions for a single person taking a round trip from Oslo to Gran Canaria to be about 1200 kg when all emissions and indirect effects at high altitude are accounted for. This estimate is based on the emission factor database DEFRA (2019) by assuming flying long-haul with economy class. In addition to the flights come the services that are available on Gran Canaria, including meals and transport. Gran Canaria has a high emissions intensity of electricity supply, using natural gas and oil for power generation (Tomorrow, 2020), and all services purchased by vacationers will be supported by this power supply. Further, very low average rainfall has led Gran Canaria to produce water using desalination, which is very electricity intensive (Alonso et al., 2015). Without coming to a final, precise figure for emissions associated with a holiday in Gran Canaria, it is clearly very high.

Turning to private cabins, there is very large variation in types and sizes of cabins, how often then are in use, the distance from owners' and users' homes, and services available in the vicinity of the cabin. A trend in recent years is for the construction of larger cabins, with quality much more similar to the owners' main residence. Here we take as an example a private cabin constructed recently to high, modern standards with an area of 60 m^2 in Hemsedal. We show later in the section that emissions from construction and maintenance of such a cabin are about 400 kg CO2-eq. per year over the lifetime. The distance between Oslo and Hemsedal is 201 km, which leads to direct emissions of 53 kg OC2-eq. for a roundtrip given an average Norwegian car in 2020 (HBEFA3.3, 2017). Using an electric car would reduce transportation emissions of well-to-wheel by about 90%.

Construction of every new cabin leads to emissions. In typical LCA calculations of single-family residence houses in Norway the house is assumed to contain 240 m^2. With recent building standards (TEK17) and standard calculations[1], construction, maintenance, and disposal after 60 years will lead to emissions of about 75 tonnes CO2-eq., while transportation during construction will add another 14 tonnes CO2-eq. Emissions from the use stage is also substantial, but the level dependent on the assumptions of the electricity mix. Energy usage during usage over 60 years may be as low as 40 tonnes CO2-eq. with a green Norwegian electricity mix and as high as 240 tonnes CO2-eq. with generic electricity mix. Travel to and from the house adds also up and may be as large as 300 tonnes CO2-eq. over the lifetime assuming technological improvements, but no changes in travel pattern for a house in the vicinity of Oslo. For construction, maintenance, and energy usage, the total emission is 129 tonnes CO2-eq. over the lifetime, or 540 kg CO2-eq per person and year if the household has four members.

In such model calculations, a cabin is assumed to be a quarter of the size of a house, or 60 m^2 with the standard TEK10. The emissions from construction and maintenance of such a cabin is about 30% of that of the house, or 25 tonnes CO2-eq. Hence, owning your own cabin leads to emissions of more than 400 kg CO2-eq. per year over the lifetime, with energy consumption in the cabin and transportation to and from will add on to that.

The cabins run by DNT have also been built at one stage. The standard is often lower, indicating low emissions, while also often built more remotely, which will increase the transportation emissions. Often new private cabins are built in quantity, dozens at the same site, while a DNT cabin sits alone, substantially reducing economies of scale in transportation during construction and also provision of infrastructure. On the other hand, DNT cabins' emissions are shared between thousands of users, effectively resulting in lower 'per capita' emissions than a private cabin.

Emissions from one trip to Gran Canaria are high, while the same can also be said about building a new cabin. The different cases present here are difficult to compare, as they provide quite different 'services'. But simply put, if holidays are taken more locally in shared accommodation such as DNT cabins instead of on distant shores such as Gran Canaria, then emissions connected to the holidays would likely be substantially lower.

3.4 Car sharing

The last type of sharing to be discussed in this report is car sharing. Our illustrative scenario of potential emission effects is on a family of two adults and two children with travel habits near the average. The daily travel is based on the National survey of travel behavior (Hjorthol et al., 2014). Our illustrative family lives near Oslo, where both parents travel 16.2 km to work and the children 7 and 12 km to school. The family does also some additional trips to shop, visit and leisure activities. Most of the travel is done by car (70%), but also by public transport (20%), and walking and biking (10%). The family goes for a longer shopping trip (distance 20 km) every second week and to the cabin in the mountains (distance 230 km) every third week.

We compare this illustrative scenario with two alternatives, one where they replace the car with car sharing and one where they replace with electric car sharing. In both alternatives, we assume that some of the daily travel by car is replaced by public transport, walking, and biking due to less access to a car.

Emissions are estimated on a well-to-wheel basis in order to make emissions from electric cars comparable with the other transportation modes. Construction of the vehicles and infrastructure is not included in the well-to-wheel emissions. As emissions are higher from producing an electric car than from producing a similar car running on gasoline or diesel, the emissions reductions from electrification would be somewhat smaller than shown here if we considered LCA emissions.

Emissions of an average Norwegian car in 2020 is based on HBEFA3.3 (2017), with 18% added to account for fuel extraction, production and transport, giving 155 g CO2 per km. For simplicity, we

[1] NS3720, method for greenhouse gas calculations for buildings

assume the CO_2 emissions from public transport to be line with the reported emissions from the busses operated in the area, which was 33 g CO_2/person km when accounting all emissions from well-to-wheel (Ruter, 2018). The electric car may have emissions of about 12 g CO_2/km when assuming a Nordic electricity mix of 60 g CO_2/kWh (CICERO et al., 2012; Nordic Energy Research, 2018).

This family has emissions of almost 15 kg CO_2/day from daily travel. Those emissions are reduced to 5.5 kg CO_2/day with car sharing and to 2.3 kg CO_2/day with electric car sharing. The long trips account for 27 kg CO_2/week, not reduced in the car sharing scenario but reduced to 2 kg CO_2/week with electric car sharing. Hence, we see that car sharing may reduce emissions by especially leading to mode changing to public transport, biking, and walking, while the long trips are reduced if the car sharing is electric. The combination of car sharing and replacing fossil fuel with electric gives the largest cuts.

4 Discussion

We have presented illustrative scenarios, as well as presented some literature, of what the potential impacts on emissions sharing has. Sharing may have other benefits or disadvantages. We have not produced scenarios that look into the effects of potential institutional adaptations, for instance effects of parking fees, or stricter regulation of parking space, and of potential up-scaling, i.e. if this practice was adopted by other organizations, counties or all of Norway.

In the case of community-supported agriculture (CSA), individual transportation was highlighted as one of the largest differences in emissions compared with standard, supermarket-sourced groceries. The distances that individuals travel in their private vehicles are much more important in the total profile of emissions than the methods of food production or the mass transportation of food during distribution. Ruminant animals are another significant source of emissions, and changing diets might be expected to have a large effect on CSA-members' carbon footprints, but interviews demonstrated that some participants in CSA reduced and others increased their meat consumption as a result of membership in the scheme.

The case of shared tools has shown that despite the apparent fact that certain tools are rarely used, the emissions gains from sharing these tools is very minor. This is because the emissions associated with production and transportation of these tools are small in the broader context of a household's emissions. This is not to say that sharing of such tools is of no consequence, but that the outcome for emissions is very small.

The second example of shared equipment was with trailers. Being more substantial than electrical tools, with a large steel component, construction emissions are relatively high. However, the outcome of new community sharing of trailers is highly uncertain given that community sharing of trailers already exists (via petrol stations, for example), and these new trailers might simply result in more trailers being constructed.

For electric bicycles, the use-phase emissions are almost insignificant compared to use of a private vehicle, and the introduction of shared electric bicycles demonstrated the potential for high annual reduction in emissions by replacing journeys in passenger cars.

For sharing of cabins, we compared with use of private cabins and a typical holiday to Gran Canaria. Emissions from a holiday to Gran Canaria were shown to be very high, but the construction of a new cabin are even higher. However, once a cabin is constructed, the use-phase emissions may be low, depending on transportation used to reach the cabin, while every trip to Gran Canaria accumulates emissions. The shared DNT cabins, with emissions spread over a much larger number of people, resulted in the lowest addition to an individual's footprint.

Finally, car sharing can lead to substantial reductions in emissions resulting from reduced construction-phase emissions when fewer cars are in the national fleet, mode change because of changed accessibility to transport options, and lower long-distance emissions when shared electric cars replace private fossil-motor cars.

Further to all these direct emissions consequences are the potential learning effects, as communities become more familiar with the practicalities of sharing and become more conscious of the consequences of their actions on the environment. However, as this study has suggested, there can be substantial differences between perceived and real effects, and there remains the danger of perverse outcomes from well-intentioned actions. One theme through several of the case studies in this report is private transportation, which generally results in substantial emissions because of the energy required to move not just the individuals but the vehicle. For example, it appears to be counter-intuitive to many that transporting food long distances over the oceans can result in lower per-person emissions than driving once to the supermarket.

Clearly community sharing has consequences beyond emissions of greenhouse gases, such as animal welfare, sustainability of soil use, local community identity, among many others. These are also very important issues and should be taken into consideration when designing and evaluating sharing schemes.

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